Wind direction frequency, and frequency resultant for the 13 years, 1891–1902—Continued

SAVANNAH, GA.

	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm	Frequency resutant	
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*Dir.*	*P. ct.*
January	12	15	6	4	7	15	18	20	------	n 54° w	28
February	10	13	7	7	10	15	17	20	------	n 70° w	21
March	8	10	9	10	18	16	13	16	------	s 45° w	18
April	8	8	9	12	23	14	13	12	------	s 22° w	20
May	6	8	9	15	25	17	12	8	1	s 8° w	30
June	6	8	10	18	25	20	9	4	------	s 4° e	37
July	6	7	6	12	21	30	13	5	1	s 27° w	41
August	7	9	8	12	22	24	12	7	1	s 20° w	31
September	11	26	17	15	11	8	6	4	1	n 83° e	31
October	20	29	11	8	6	5	7	12	------	n 29° e	38
November	17	18	8	8	8	11	12	17	1	n 14° w	20
December	16	16	8	7	9	12	13	18	------	n 29° w	21

Wind direction frequency, and frequency resultant for the 13 years, 1891–1902—Continued

WASHINGTON, D. C.

	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm	Frequency resultant	
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*Dir.*	*P. ct.*
January	12	11	5	6	18	7	10	28	3	n 52° w	21
February	14	11	5	6	14	7	10	30	2	n 44° w	28
March	13	13	8	8	17	5	8	27	2	n 29° w	17
April	11	12	7	11	18	6	8	26	2	n 45° w	14
May	10	12	8	10	25	8	8	18	2	s 26° w	7
June	12	11	6	10	24	11	9	16	2	s 47° w	11
July	9	8	5	9	29	12	10	16	3	s 36° w	21
August	14	12	7	9	23	8	8	16	4	s 80° w	3
September	13	13	9	10	21	9	7	15	3	s 61° e	3
October	14	15	6	7	18	6	8	23	4	n 26° w	15
November	13	9	4	6	23	6	9	28	3	n 71° w	20
December	13	7	4	6	22	8	11	26	3	n 89° w	27

THE DEPENDENCE OF COASTAL SEA TEMPERATURES OF CAPE COD ON THE WEATHER

By FRANCES VANDERVOORT TRIPP

The purpose of this study is to ascertain the temperatures of the ocean water surrounding Cape Cod and to discover to what extent the agents, sun, wind and air affect these temperatures. Observations were made at six stations during the summers of 1925 and 1926, three located on the north, three on the south side of the cape. (See map, fig. 1.) Of those on the north side, the first, Barnstable, is situated on Barnstable Harbor, where the tidal rise and fall is between 9 and 10 feet; the second, Sandy Neck Point, forms the entrance to Barnstable Harbor; the third, Scorton Dunes, is located on the outside of Sandy Neck.

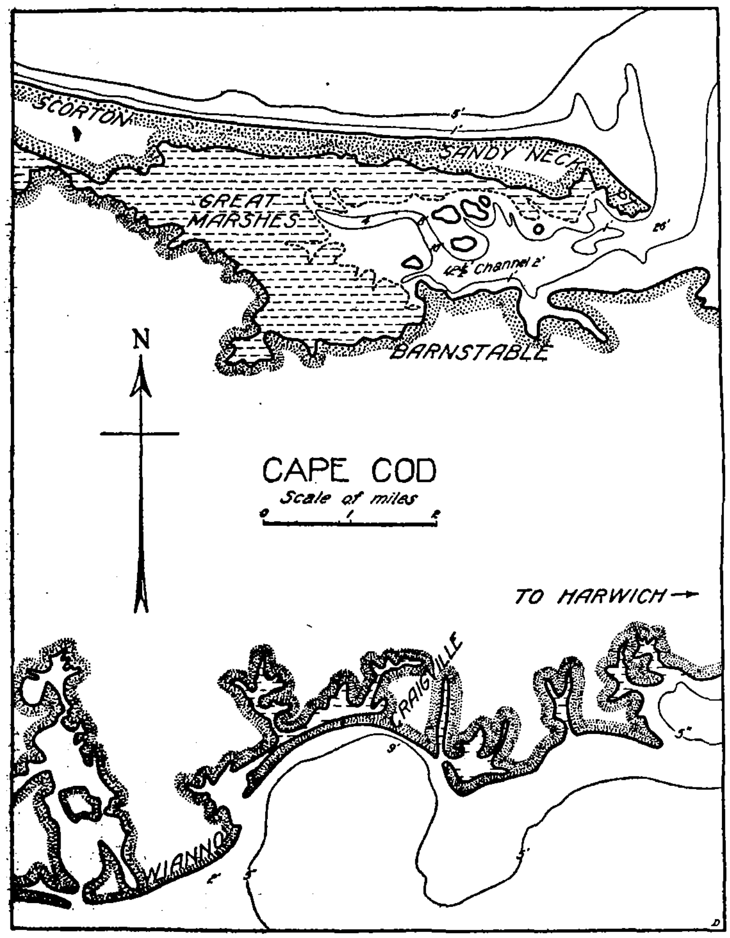


FIG. 1.—Map of Barnstable and vicinity

All three have deep water at high tide, the first two have exposed flats at low tide. At the fourth station, Craigville, on the south shore, the rise and fall of tide is negligible, the water is always deep; while at the fifth and sixth stations, Harwich and Wianno, with the exception of flood tide, the water is never deep. Conditions at Harwich and Wianno being similar, data from these two stations may be grouped together.

To obtain the water temperatures, a Fahrenheit thermometer was placed inside a heavily weighted ginger-ale bottle which was lowered into the water by a 5-foot string attached near its mouth. After it had filled at that depth it was raised and the thermometer read. All temperature readings not made at that depth are so designated. The time required for the bottle to sink was 4 seconds, required to sink and fill, 22 seconds, required to fill just below the surface, also 22 seconds. The bottle was one-sixth full on reaching the bottom. Owing to the great rise and fall of tide and consequent rapidly moving water in Barnstable Harbor, where most of the observations were taken, the difference in temperature between the surface and 5 feet is in a majority of cases negligible.

Because of the contour of the coast line and its relation to the cold drift from the north, the water along the sandy shores of Cape Cod falls naturally into four divisions: (1) North shore, deep; (2) north shore, shallow; (3) south shore, deep; (4) south shore, shallow. The average summer temperature of the north shore deep ranges from 63° to 66° (the higher figure being found where sunned flats have influence); the average summer temperature of the south shore, deep, remains fairly constant at 74°–75°. Shallow-water temperatures vary more, depending on the interrelation of the factors, sun, wind, and air. To determine the sequence in importance of these factors in influencing local shore temperatures, high-tide temperatures at Barnstable (deep water, north shore, influenced somewhat by sunned flats) will be considered in relation to each factor in turn.

INSOLATION

The greatest number of high-water temperatures came on clear or hazy days; 22 examples of water at 70°–75° occurring on such days, against 14 on partly cloudy and cloudy days. The lowest temperatures and the greatest number of temperatures below 65° were recorded on partly cloudy and cloudy days; there were 16 instances of water 59°–65° on such days, against 11 on clear days. Water below 65° on clear days was due in practically all cases either to an exceptionally strong offshore wind or to the chilly northeast wind which prevailed August 15–September 15, 1926. The average water temperature on clear and hazy days, as shown by 78 observations, was 67.6°; on partly cloudy and cloudy days, as shown by 45 observations, was 66.6°, a difference of 1°.

The lag in the effect of cloudiness is shown in the table next following. Table 2 illustrates the steady fall in water temperature in cloudy weather, wind and air conditions being similar.

The following table shows that the effect of cloudiness is felt 24 hours later rather than on the day it occurs.

TABLE 1.—*Water temperature and cloudiness at Barnstable*

Date	Sky	Temperature		Water 24 hours later
		Air	Water	
1926		° F.	° F.	° F.
July 14	Cloudy	59	68	64
30	do	70	68.8	64
Aug. 5	do	70	72	68
18	do	64	68	65
19	do	64	65	62
25	do	68	65	61.8
Sept. 2	do	60.5	64	62

Table 2 illustrates the effect of continued lack of sunshine on the water, wind and air conditions being similar.

TABLE 2.—*Water temperature and continued cloudiness at Barnstable*

Date	Sky	Temperature		Wind
		Air	Water	
1925		° F.	° F.	
Sept. 14	Cloudy	72	71.5	SW. 1.
15	do	65	69	NE. 2.
16	do	63	63	NE. 2.
17	do	59	59.5	NE. 4.

The effect of continued clear skies, air and wind remaining fairly constant, is illustrated in Table 3.

TABLE 3.—*Water temperature and sunshine at Barnstable*

Date	Sky	Temperature		Wind
		Air	Water	
1925		° F.	° F.	
Aug. 2	Clear	73	65	SW. 3.
3	do	74.5	68	N. 3.
4	Hazy	78	68	Calm.
5	Clear	76	69	SSW. 1.
8	do	75	70	N. 1.

WIND

Wind is the most active agent in changing surface temperatures. On July 22, 1925, after the wind had blown offshore for 12 hours with a force increasing to 9 on the Beaufort scale, the water temperature fell from 72° to 60° and remained low through July 27. At Craigville, on the south shore, it rose 4° from 74° to 78° during this same period of high onshore winds. This change was the greatest noted on the south shore. During the period August 21, 22, and 23, 1925, the water temperature at Barnstable fell from 70.1° with the wind blowing from the northeast, force 1, Beaufort, to 67° when the wind changed to north, and rose again to 69° when the wind shifted to south, force 4. On these days the sky was clear and the air temperature uniform. The water temperature at Craigville when the wind was north, force 6 (a high offshore wind), fell 1°.

From the 15th of August, 1926, until records ceased to be kept, the prevailing wind direction was northeast and the air temperature low. In spite of clear skies, the water temperature at Barnstable under such conditions fell:

	° F.
Aug. 15	74
16	73
17	68
18	65
20	62
22	60.8

Nor did it again rise above 66° except in the late afternoon.

The data for both years show that the highest water temperatures are recorded when wind of low velocity is blowing from the south or west.

AIR AND WATER TEMPERATURES

The graphs of air and water temperatures for the two summers show clearly the general relationship between these two (see fig. 2). The water curve does not coincide

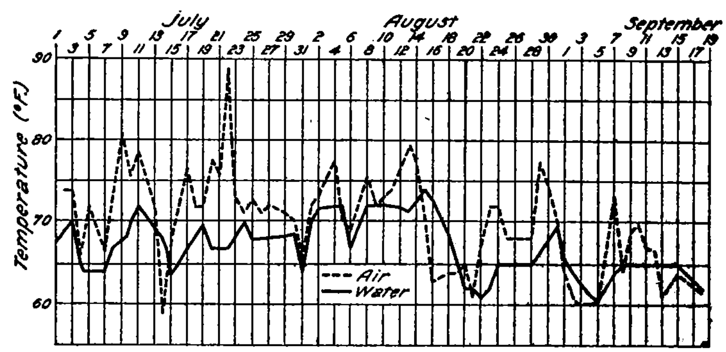


FIG. 2.—Air and water temperatures at high tide, 1926

with the air curve, but follows it with a slight lag and less amplitude. That is, when the air temperature rises, the rise in the water temperature curve is not so prominent, and its peak lags about 24 hours behind that in the former. This is to be expected largely for the reason that volume for volume water has about 3,300 times the thermal capacity of air.

TABLE 4.—*Delayed effect of air upon water temperature, Barnstable*

Date	Sky	Temperature		Time
		Air	Water	
1926		° F.	° F.	
July 22	Clear	89	67	10 a. m.
23	do	73	68.5	10:30 a. m.
24	Rain	71	70	11 a. m.
25	Clear	73	68	12 m.
Aug. 13	Partly cloudy	80	71.5	4 p. m.
14	do	78	73	Do.
15	Clear	69	74	5 p. m.
16	Rain	63	73	6 p. m.
18	Cloudy	64	68	9 p. m.

It is seen from the above data, then, that although wind can make the greatest change in the shortest time, the sun is the most important factor in controlling water temperature and that air and water coincide in general trend.

THE SHALLOW WATER OF THE NORTH SHORE

Tidal stage.—There is no shallow water at high tide either in Barnstable Harbor or at Sandy Neck, the observational points on the north side of the cape (i. e., when the tide is full the water is 5 to 6 feet deep at a distance of 10 feet from the shore). From low to half tide, however, shallow water rises over flats which, if the sun is shining, modify its temperature. Indeed sunned flats are the all-important factor in influencing water temperatures where the depth of the water is less than 2 feet; wind and air are relatively unimportant. The following data show the temperature changes in water rising over sunned flats (water 0 to 2 feet deep):

TABLE 5.—*Temperature changes in rising water*

I. Water rising over flats, Sandy Neck, July 9, 1925, morning. Air, 69°; wind, NW., 2; sky, clear; temperature of dry sand, 89°.

Water temperature	Depth
° F.	
81	1–2 inches, sunned pool.
80	6 inches.
79	6 inches, farther from shore.
73	18 inches.

Temperature of deep water, 66°.
Average departure from deep water, 12.2°.

II. Water rising over beach, Barnstable, July 20, 1925, morning. Air, 80°; wind S., 1; sky, clear; temperature of dry sand, 95°.

Water temperature	Depth
° F.	
80	1 inch.
73	8 inches.

Temperature of deep water, 69.5°.
Average departure from deep-water temperature, 7°.

NOTE.—The average departures in the first case are greater than those in the second case because the water in the first case is spreading over a broad expanse of almost flat sand, while that in the second is rising rapidly over a shelving beach. These figures show that differences in air temperature and wind velocity make little difference in the temperature of shallow water if the sun is shining.

III. Water rising over beach, Barnstable, July 23, 1925, noon. Air, 76°; sky, clear; wind, SW., 2.

Water temperature	Depth
° F.	
73	8 inches.
77.1	14 inches.

Temperature of deep water, 63°.[1]
Average departure from deep-water temperature, 9–10°.

[1] The temperature of the deep water is lower than usual owing to the high offshore wind velocity of July 22. This difference in deep-water temperature, however, seems to make no difference in the temperature of the shallow water.

THE SHALLOW WATER OF THE SOUTH SHORE

Observations made during both summers show the average shallow-water temperature at West Harwich and Wianno to be 77.1°. The average deep-water temperature at Craigville is between 74° and 75°.

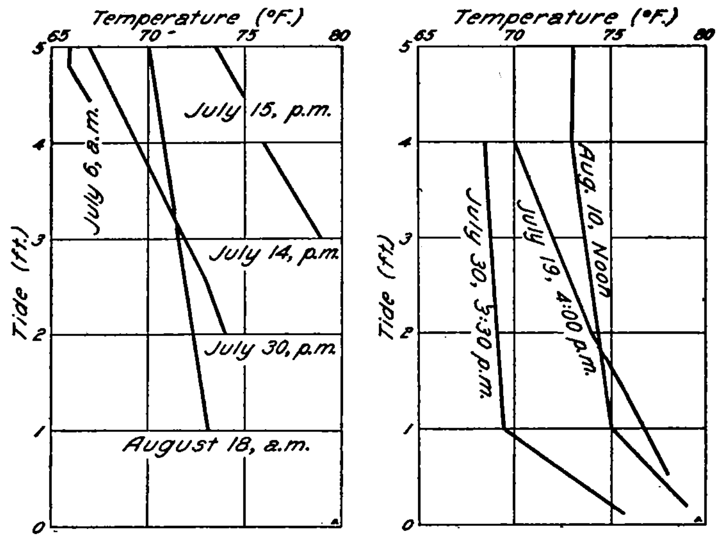
Harwich and Wianno water is warmer than Barnstable water for three reasons:

1. The general body of water south of Cape Cod is warmer than that north of the cape.
2. The water at both places is always shallow, so that the sun's rays penetrate it.
3. Harwich water rises over a broad expanse of sunned flats.

THE DEEPER WATER ALONG THE NORTH SHORE AT BARNSTABLE AND AT SANDY NECK

Tidal stage.—High-tide temperatures only will be considered here. Again, the question of sunned flats seems to be the all-important one, as the following comparisons show.

Sun and high-tide temperatures.—That the sun has immediate effect upon water temperatures is shown by the following figures. The average temperature on clear days is 67.4°; the average for cloudy days is 65.9°; a difference of 1.5°. The effect of sunshine upon water



FIGS. 3 AND 4.—Left, falling temperature with rising tide; right, difference in temperature between deep and shallow water at the same time high tide

24 hours later is even more marked; 68.8° is the average water temperature 24 hours after a clear day; 66.2°, 24 hours after a cloudy day, a difference of 2.6°.

The diurnal warming of sunned flats is shown by a comparison of clear-day morning and afternoon high-tide temperatures of July and August. Twenty-seven observations in the forenoon show an average of 67.4°, and an equal number in the afternoon (after 2 p. m.) show an average in the afternoon of 70.4°, a gain in the afternoon of 3°.

Falling temperature with rising tide.—The fact that the water temperature falls with rising tide shows (1) the effect of sunned flats in warming shallow water, which ceases as the water deepens, and (2) the thinness of any surface layer warmed appreciably by the sun, for, owing to the turbulence in the rising water, this thin layer soon becomes absorbed; that is, where there are no flats the temperature falls somewhat with rising tide because of this turbulence, but where the effect of flats is added the fall is greater (see fig. 3). Figure 4 shows the difference between deep and shallow water at the same time at high tide.

Wind and high-tide temperature.—The following statement shows the general relationship between wind and water:

Wind direction	Average temperature	Remarks
	° F.	
South, west, southwest	68.4	Weather usually fair.
Northwest, north	67.5	Weather usually fair but cold.
Northeast, east, southeast	66.1	Weather usually stormy.

The highest water temperatures occur with south or southwest winds of low velocity (temperatures over 70°). An offshore wind of high velocity, even though it be south, may lower the temperature as much as 12° in an equal number of hours.

In general it may be said that wind and air temperature go hand in hand and affect water temperature 12 to 24 hours after they themselves are felt; that is, on the first day of a cold wind the water remains warm, while on the second day it grows cooler.

THE DEEPER WATER ALONG THE SOUTH SHORE AT CRAIGVILLE

The lack of sunned flats, the constant deep water within 3 to 4 feet of the shore, and the absence of marked tidal rise and fall at Craigville all combine to keep the water temperature remarkably even at 74°–75°.

TABLE 6.—*Temperature readings at Craigville*

Date and time	Temperature		Suggested cause of deviation from 74°–75° F.
	Air	Water	
	° *F.*	° *F.*	
July 24, 1925, p. m.	79	78	High on shore wind of July 22.
28, 1926, a. m.	70	76	
Aug. 1, 1925, a. m.	78	75	
2, 1925, a. m.	72	73	
15, 1926, p. m.	79	78	Continued high air temperature.
18, 1926, a. m.	------	74	Rain for 3 days; lowered temperature.
23, 1925, a. m.	72	73	North wind for 2 days.
Sept. 11, 1926, a. m.	------	68	Persistent northeast wind and low air temperature.
18, 1925, a. m.	61	69	Rain and northeast wind for 3 days.

NOTE.—The afternoon temperatures seem to run slightly higher than the morning temperatures. This fact is doubtless due to the heating of the water by the sun, the higher afternoon air temperature, and the onshore sea breeze which blows the heated surface water toward the shore.

TABLE 7.—*Comparison of Craigville and Barnstable air and water temperatures*

Date	Craigville				Barnstable			
	Time	Wind	Air	Water	Time	Wind	Air	Water
1925			° *F.*	° *F.*			° *F.*	° *F.*
July 11	5 p. m.	SW. 1	76	74	12 m.	S. 1	81	69
23	4 p. m.	SW. 5	------	78	4 p. m.	SW. 5	79	63
Aug. 1	11 a. m.	S. 1	78	75	3 p. m.	S. 5	78	67
2	10:30 a. m.	SW. 3	73	73	11 a. m.	SW. 3	72	65
23	3 p. m.	S. 4	------	73	11 a. m.	S. 1	72	69
Sept. 18	12 m.	SE. 3	61	69	12 m.	SE. 3	------	63
Average	------	------	------	73.6	------	------	------	66
Average difference	------	------	------	7.6				

To summarize conditions briefly, it may be said that (1) the highest water temperatures at Barnstable occur in the afternoon, on sunny days, when the air temperature is above 70° F. and a gentle wind is blowing from the south or west; and conversely, the lowest water temperatures come in the morning, on either sunny or cloudy days (preferably the latter), when the air temperature is below 65° F, and the wind is blowing from east, north, or from the south with high velocity; (2) where they are found, sunned flats are the all-important factor in affecting the water temperatures; wind of high velocity is the most radical agent; air exerts the steadiest influence, although it is often obscured by the absence of sun or the presence of a high wind.

THE CLIMATIC REGIONS OF NORTH AMERICA

By W. VAN ROYEN

[Clark University, Worcester, Mass.]

The accompanying map is the result of an attempt to apply the principles used and explained by Köppen in "Petermanns Mitteilungen," 1918, (1) and later in "Die Klimate der Erde" (1923), (2) to the data found in the publications of the United States Weather Bureau and the Canadian Meteorological Service.

The map, given in "Petermanns Mitteilungen" and reprinted in black in "Die Klimate der Erde," is of too small a size to show details. Futhermore, the projection used for it distorts the features of North America too seriously to give a clear idea of the distribution of the different climatic zones over this continent.

The study had to be restricted to eastern North America north of the Rio Grande; the data available for Mexico were not sufficient to make a better approximation to a true representation of the conditions than is found on Köppen's map. Also, the number of stations with long records in the area between the Rocky Mountains and the Sierra Nevada and the Cascade Range is inadequate, especially in connection with the great topographical complexity of this region. An attempt to work out Köppen's principles for this partwould necessarily have to be supplemented by observations of the vegetation in the field to fill out the gaps between the stations.

This has been done by R. J. Russell for the State of California in his "Climates of California." (3)

The above mentioned studies of Köppen,[1] and some of his publications in the Meteorologische Zeitschrift, (4, 5) have served as basis for this study.

I have used also Bulletin W of the United States Weather Bureau, the Monthly Records of Meteorological Observations of the Meteorological Service of Canada, "The temperature and precipitation of Alberta, Saskatchewan, and Manitoba," by A. J. Connor, (6) and Hann's "Handbuch der Klimatologie." (7)

To determine the division lines on the map, more than 300 stations with long records have been used. It was necessary, moreover, to compare the data of many other stations in order to ascertain that some of the values were not due to local conditions and that they increased or decreased regularly to the one or the other side. The use of stations with shorter records than 10 years has been avoided as much as possible.

As Köppen states, climatology has to work with quantitative magnitudes. But those magnitudes in themselves do not have a practical value, and therefore a system of classification built on limits chosen entirely arbitrarly would likewise have no practical value. So we have to look for a parallelism between certain numerical facts or a certain combination of those facts and the phenomena of the organic or inorganic realm of nature. We can not expect more than a parallelism; it is impossible to express life in an exact mathematical formula.

Köppen considers the vegetation as the best object with a practical value for furnishing those limits.

The most important factors to be considered in this connection are:

(*a*) Whether rest periods, or at least periods of very restricted organic activity, are present.

(*b*) The duration of the period favorable for organic life.

(*c*) The conditions during that period.

These factors were kept in view constantly by Köppen in determining his criteria.

[1] *Vide*: Preston E. James, Köppen's Classification of Climates: A Review, MONTHLY WEATHER REVIEW, February, 1922, 50: 69–72.